Current Status & Future Plans for the TRIUMF-ISAC Radioactive Ion Beam Facility

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TRIUMF-ISAC

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Outline

- **What we are**
- **What we do**
- **How we do it**
- **What we would differently (now that we know better)**

What We Are
The TRIUMF-ISAC Facility

TRIUMF

- 500 MeV variable energy H^- cyclotron
- Simultaneous extraction of multiple p^+ beams

ISAC (Isotope Separator Accelerator)

- Dedicated ≤ 100 μA 490 MeV p^+ beamline
- 2 target stations running in repertory
- Shared 2 magnet mass separator
- Low energy experimental area, ≤ 60 keV
- Medium energy RIB accelerators:
  - RFQ (150 A·keV, A/q ≤ 30)
  - Stripper
  - DTL (0.15-1.5 A·MeV fully variable, A/q ≤ 6)

ISAC-II (current)

- Additional superconducting RIB linac
- Medium-β SC cavities (5 A·MeV, A/q ≤ 6)

TRIUMF ISAC

ISAC-II (future)

- 2008: Charge State Booster ($30 < A < 120$, $A/q \leq 6$)
- $\leq$ 2010: Additional high-β SC cavities (~ 8.2 A·MeV, $A/q \leq 6$)
- $\leq$ 2015: Additional low-β SC cavities ($A < 240$ with CSB)

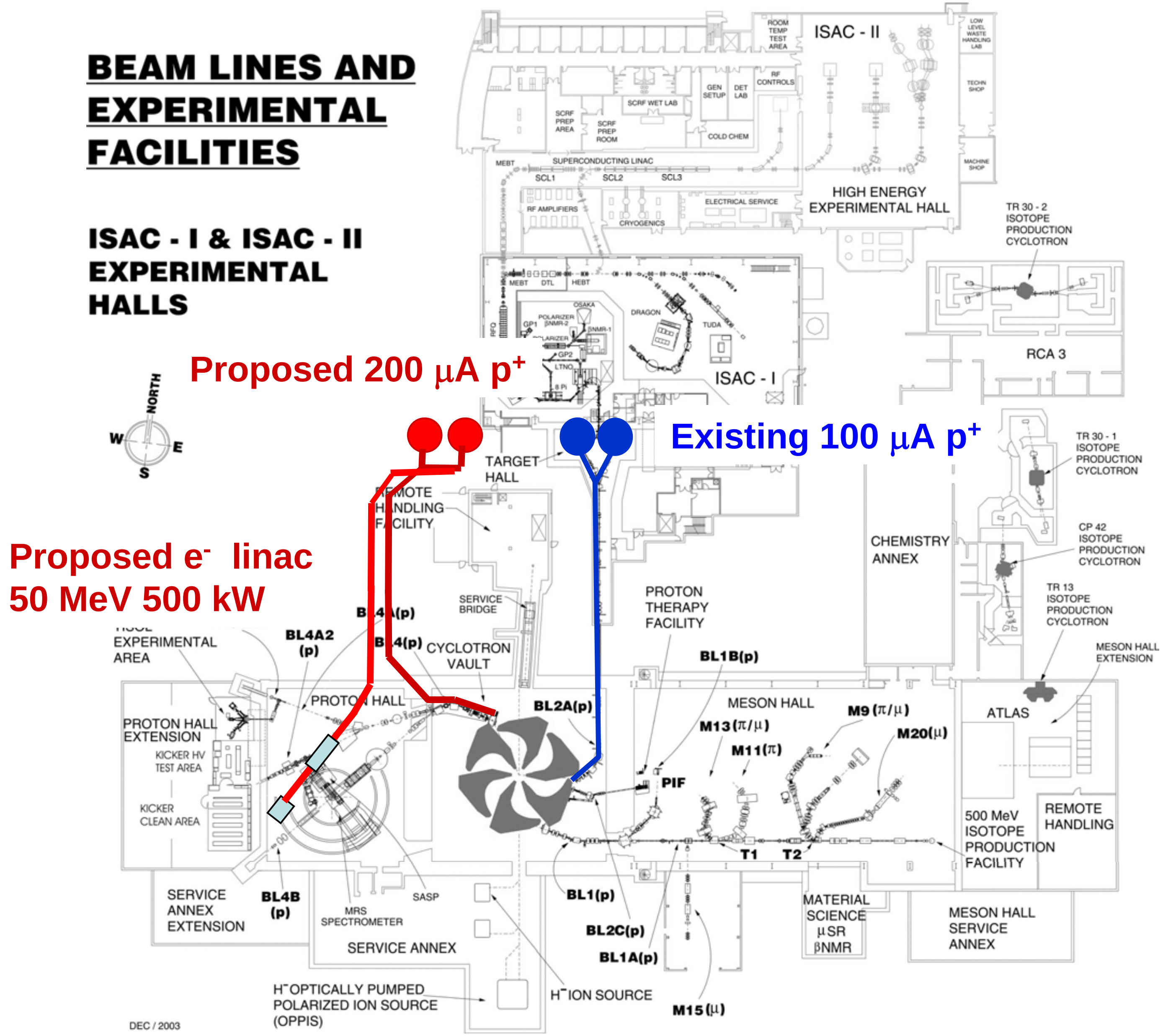
ISAC-III? (proposed for next 5 year plan)

- 2 additional target stations serviced by:
  - 2nd p^+ beamline ($\leq$ 200 μA)
  - 50 MeV 500 kW SC e^- linac for photofission on actinide targets

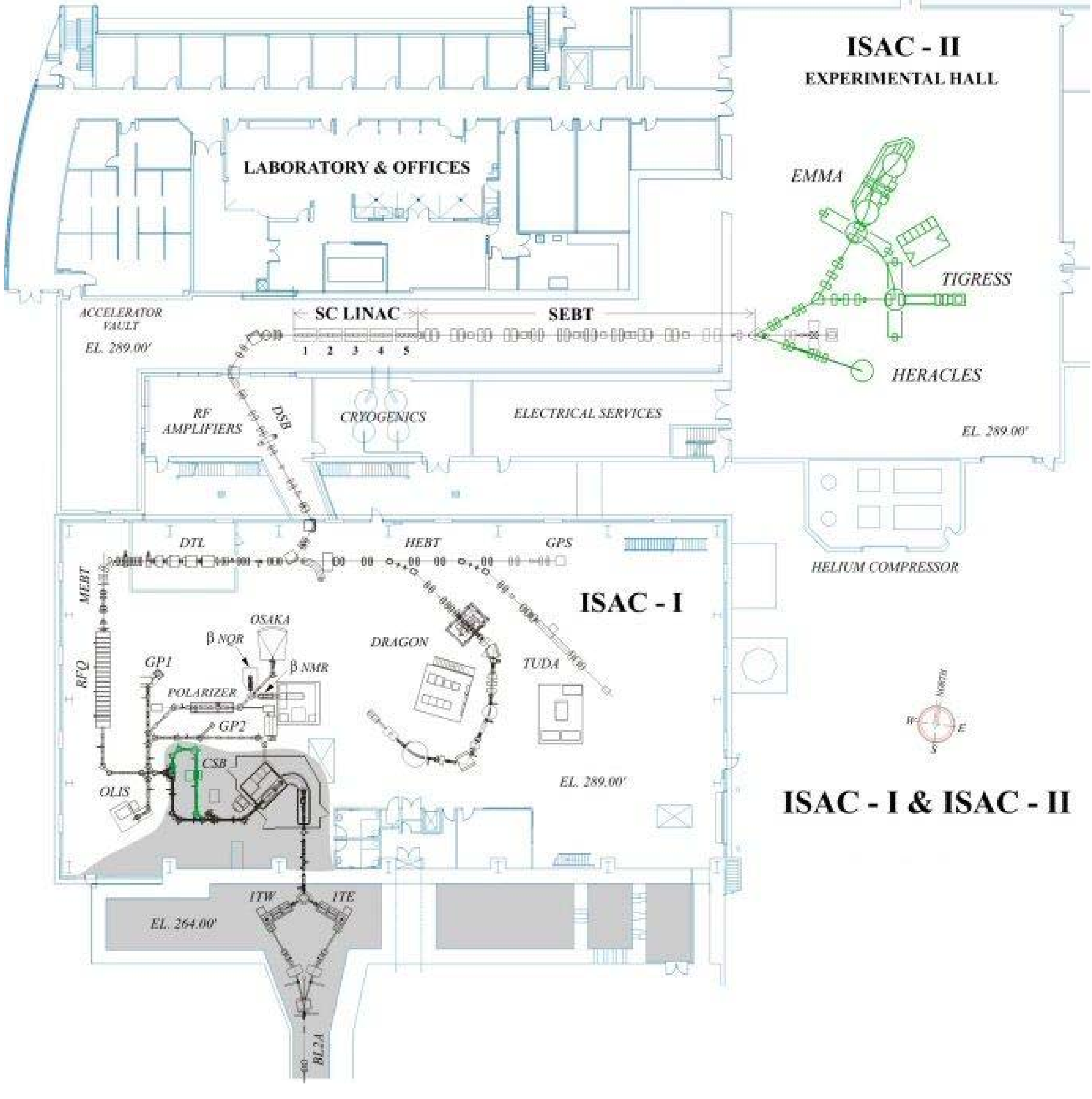
BEAM LINES AND EXPERIMENTAL FACILITIES

ISAC - I & ISAC - II EXPERIMENTAL HALLS

TRIUMF ISAC



TRIUMF ISAC



ISAC - II
EXPERIMENTAL HALL
LABORATORY & OFFICES
EMMA
TIGRESS
HERACLES
ACCELERATOR VAULT
EL. 289.00'
SC LINAC
SEBT
1 2 3 4 5
RF AMPLIFIERS
DSB
CRYOGENICS
ELECTRICAL SERVICES
EL. 289.00'
HELIUM COMPRESSOR
DTL
HEBT
GPS
MEBT
ISAC - I
OSAKA
β NQR
β NMR
DRAGON
TUDA
GP1
RFQ
POLARIZER
GP2
CSB
OLIS
EL. 289.00'
ITW
ITE
EL. 264.00'
BL2A
NORTH
W
E
S
ISAC - I & ISAC - II

Low energy ISAC Facilities

- **TRINAT: magneto-optical neutral atom trap,**
  fundamental symmetries, β-ν correlations
- **Yield measurement station:**
  HP Ge γ detector, β scintillators,
  (ΔE-E particle telescopes being installed)
- **General purpose station: $t_{1/2}$ measurements**
  Fast tape drive, β & γ counters
- **8-π spectrometer: γ-γ, β-γ decay studies**
  Compton suppressed Ge γ-detector array (20)
  SCEPTAR β-scintillator array (20)
- **TITAN: Penning trap (on line 2007)**
  Precision mass measurements (^{11}Li, ^{8}He)
- **Collinear laser polarization beam line:**
  β-NMR & β-NQR
  Osaka spectroscopy station (β, γ, n)

Accelerated Beam ISAC Facilities

TRIUMF ISAC

ISAC (≤ 1.5 A·MeV):

- **TUDA :** solid target segmented detector array
- **DRAGON:** windowless gas target,
  recoil fragment separator
- **General purpose station:**
  can accommodate temporary setups

ISAC-II (≤ 5 A·MeV):

- **General purpose station:**
  can accommodate temporary setups (MAYA, OSU)
- **TIGRESS:** 8 (32-fold) segmented clover Ge detector array
  10 in hand, 12 by 2009, more later?
- **EMMA:** recoil fragment separator
  (Funded in 2006, expected completion ~2010)

What We Do

ISAC Beams & Experiments

Low energy:

- Pure Fermi β-decay: ^{18}Ne, ^{26m}Al, ^{38m}K, ^{74}Rb, ^{62}Ga
- Spectroscopy studies: ^{51}K, ^{26,32}Na, ^{112}Ag, various lanthanides
- Neutral atom trap (TRINAT): ^{36,38m}K, ^{80}Rb
- Precision Mass measurements (TITAN): ^{8}He, ^{11}Li

Polarized Beams:

- β-NMR & β-NQR materials studies: ^{8}Li as probe (^{11}Be this year)
- Spectroscopic studies: ^{11}Li, ^{20,21,25,28,29}Na

Accelerated Beams:

- ^{21}Na(p,γ)^{22}Mg
- ^{21}Na(p,p) ^{21}Na
- ^{26g}Al(p,γ)^{27}Si (TRILIS)
- ^{18}F(p,α)^{15}O (FEBIAD)
- ^{20,21,29}Na Coulex (ISAC-II)

ISAC Experiments with Li Beams

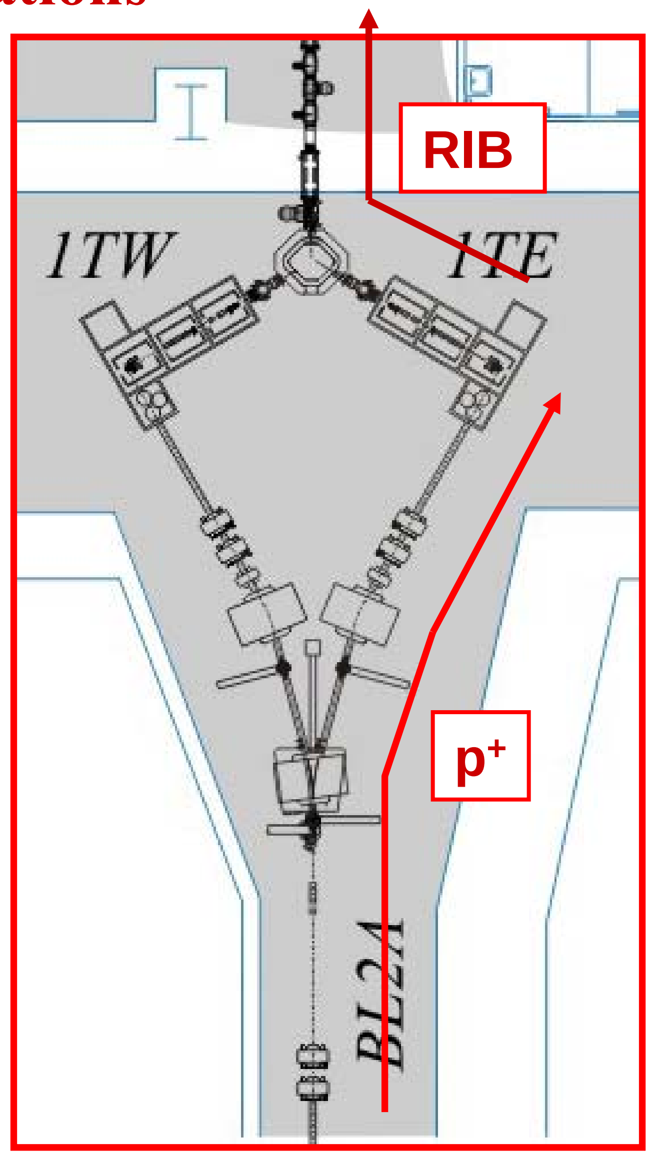
TRIUMF ISAC

- ^{8}Li β-NMR & β-NQR
- Spectroscopic studies of ^{11}Be with polarized ^{11}Li (β-γ-n)
- Laser spectroscopy determination of ^{8,9,11}Li charge radii
- Halo neutrons and the β-γ decay of ^{11}Li (8-π)
- Fusion of halo nuclei: ^{9}Li + ^{70}Zn (ISAC), ^{9}Li + ^{208}Pb (ISAC-II)
- Charged particle channels in β-decay of ^{11}Li: ^{11}Li → ^{9}Li + d (ISAC)
- ^{7}Li(^{8}Li, ^{7}Li)^{8}Li elastic transfer (ISAC)
- ^{11}Li(p,t)^{9}Li (ISAC-II)
- ^{11}Li(p,d)^{10}Li (ISAC-II)
- $^{6-11}$Li precision mass measurements (TITAN)

How We Do It
ISAC Target Stations

- Each station contains 5 shielded modules in a common vacuum tank:
  - Entrance module: p^+ beam diagnostics/collimator
  - Target module
  - Beam dump module
  - 2 modules containing RIB transport & diagnostics

- Modules are inserted/removed vertically using a remotely operated crane



ISAC Target Stations

- Each module contains:
  - A "dog legged" vacuum pumping duct
  - Electrical services duct
  - Non-hermetic "containment box"

- All services connections (vacuum, electrical, cooling) are made manually at top of module
- components in "containment box" are rad hard & are serviced remotely in a hot cell

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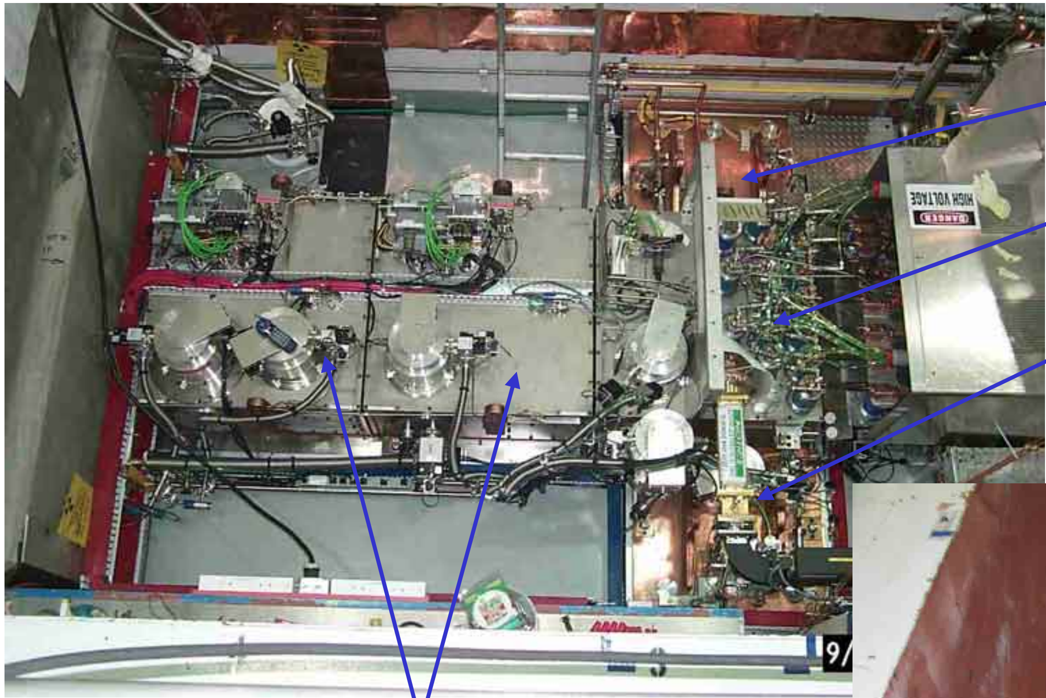
ISAC Target Module Handling

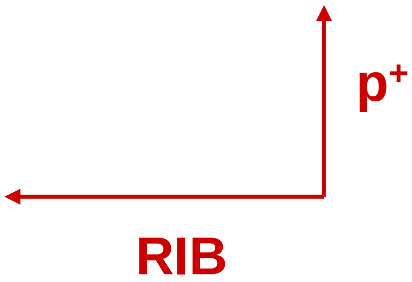


Beam Dump

Target

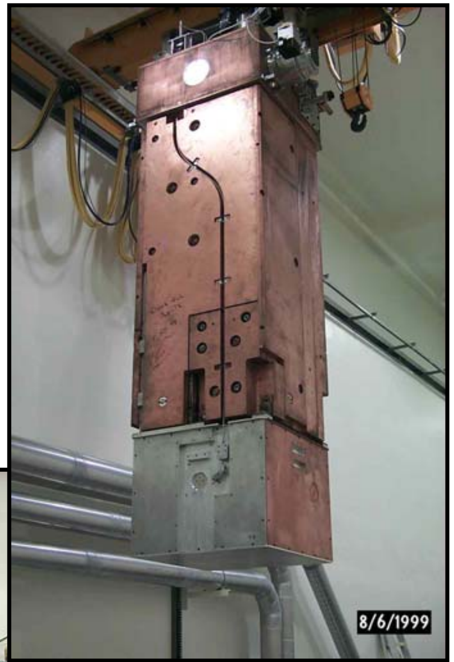
p⁺ Beam Entrance

RIB Optics & Diagnostics

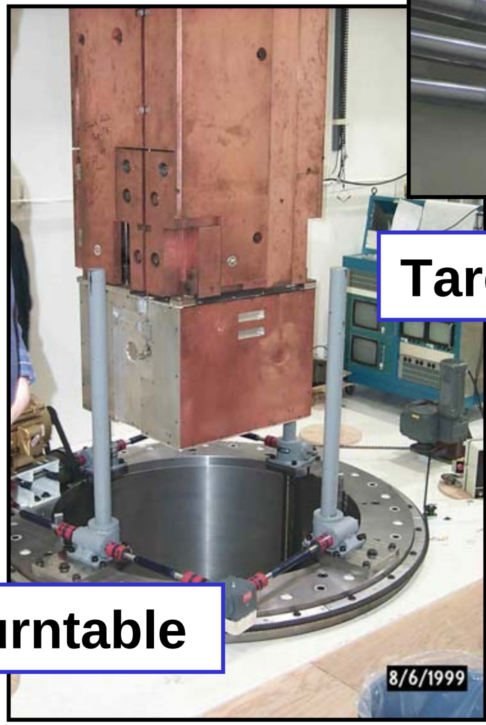


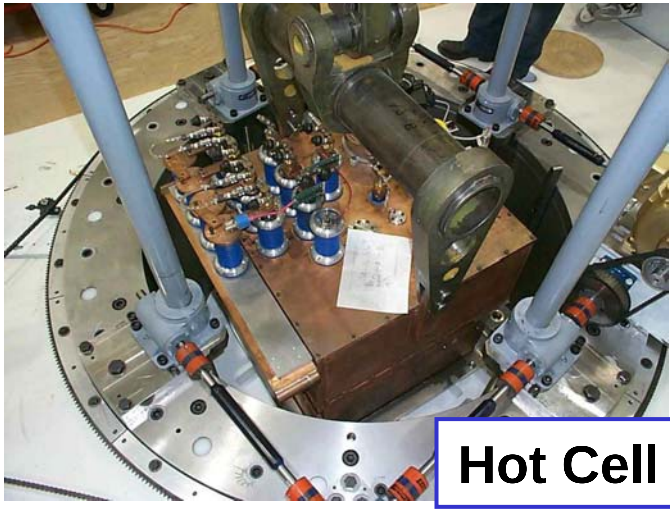
ISAC Target Module Remote Handling

RH Crane Control



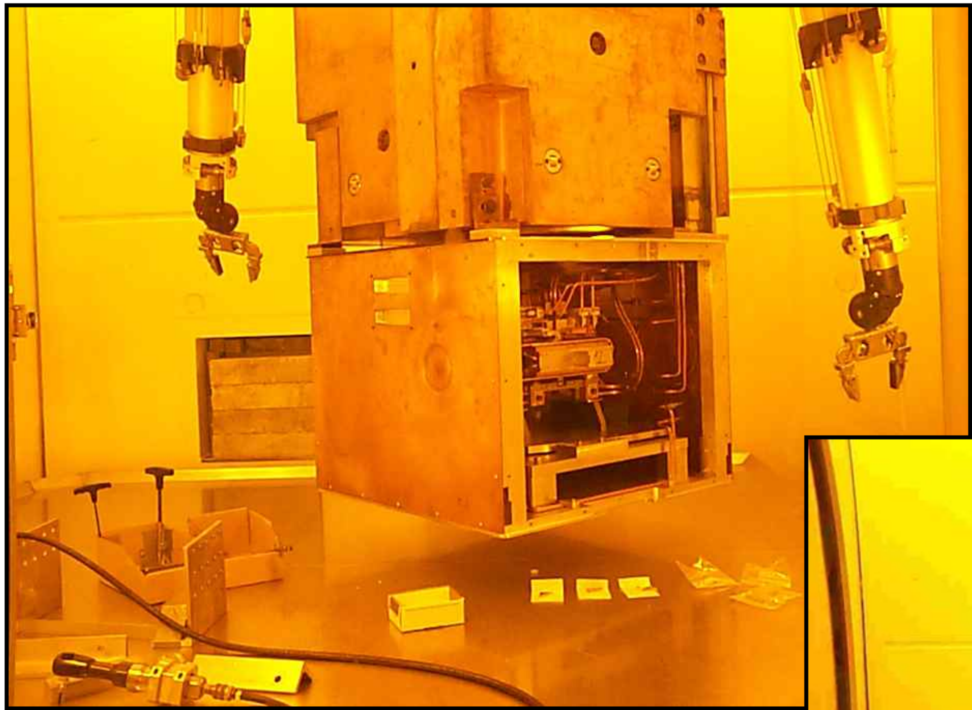
Target Transfer

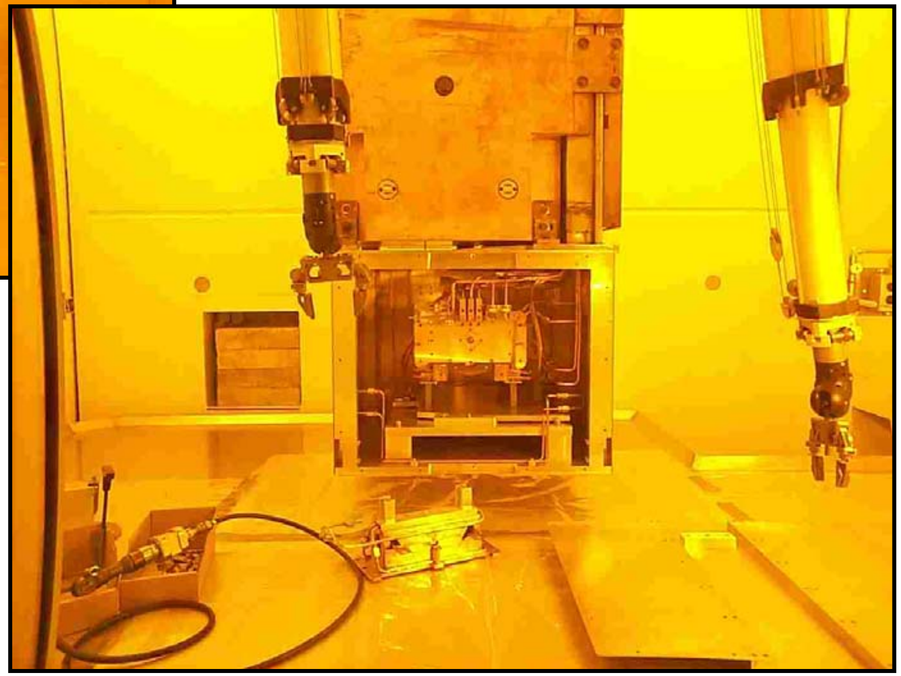




Hot Cell Turntable

ISAC Hot Cell





ISAC Target Stations (Current Problems)

- **Target module turn around time was originally ~ 2 weeks, now 3-4 weeks!**
- **≥ 3 days after EOB before we can access top of target station due to residual fields (mainly in turbo pumps)**
- **Cannot service a target station while other station is taking p^+ beam (radiation fields too high)**
- **~ 1 week required to condition targets *in situ***
  - **HV conditioning**
  - **Thermal conditioning**
- **Raising p^+ to 70 μA requires ~ 3 days**

ISAC Target Stations
(What we would do differently)

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- Hermetically sealed target module
  - Would allow for “off-line” target conditioning
  - Minimize *in situ* target conditioning time

- Remote module services connections
  - Would reduce target module installation time
  - Would reduce radiation exposure

- These modifications are proposed for future target stations

ISAC Chronology
(standard targets & surface source)

- 1996: Construction begins
- 1998 (Nov): 1st RIB delivered (1 μA)
- 1999 (July): 10 μA on Nb foil target
- 2000 (June): 20 μA on Nb foil target
- 2000 (June): 20 μA on Ta foil target
- 2000 (Nov): 10 μA on SiC pellet target
- 2001 (April): 40 μA on Nb foil target
- 2001 (July): 40 μA on Ta foil target
- 2001 (Sept): 15 μA on SiC pellet target
- 2002 (April): 30 μA on SiC/C composite foil target
- 2002 (Sept): 40 μA on TiC/C composite foil target
- 2002 (Nov): 45 μA on SiC/C composite foil target
- 2003 (May): 50 μA on ZrC/C composite foil target
- 2006 (Aug): 15 μA on Nb_5Si_3/Nb composite foil target

ISAC Chronology
(“high power” targets & other ion sources)

- **2004 (Sept): 1st high power target (Ta foils, 65 μA)**
  discovered problems with p^+ beam!
- **2004 (Dec): ZrC/C composite foil target, 35 μA, 1st TRILIS run**
- **2005 (April): SiC/C 1st composite foil HP target, 65 μA, TRILIS**
- **2006 (Nov): TiC/C composite foil HP target, 70 μA, 1st FEBIAD run**
- **2007 (June): SiC/C composite foil HP target, 75 μA, FEBIAD**

Current Status:

- **Up to 75 μA p^+ “routinely” on foil & compound carbide targets**
- **Surface, TRILIS & FEBIAD ion sources**

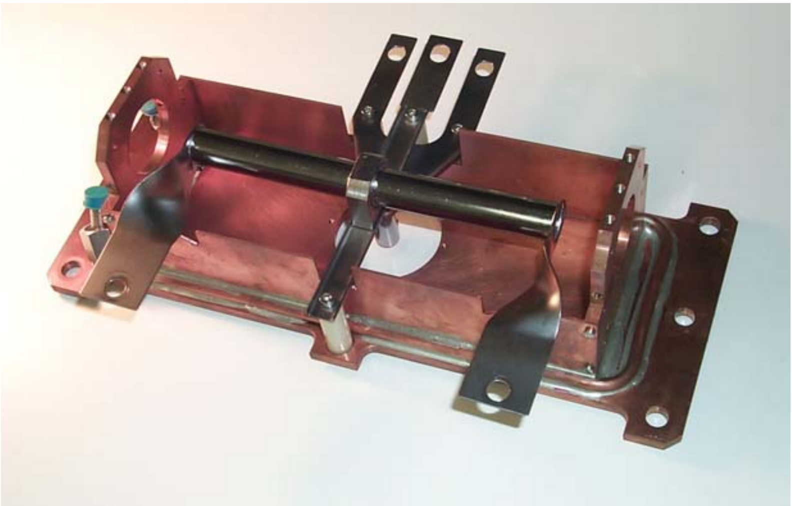
Next:

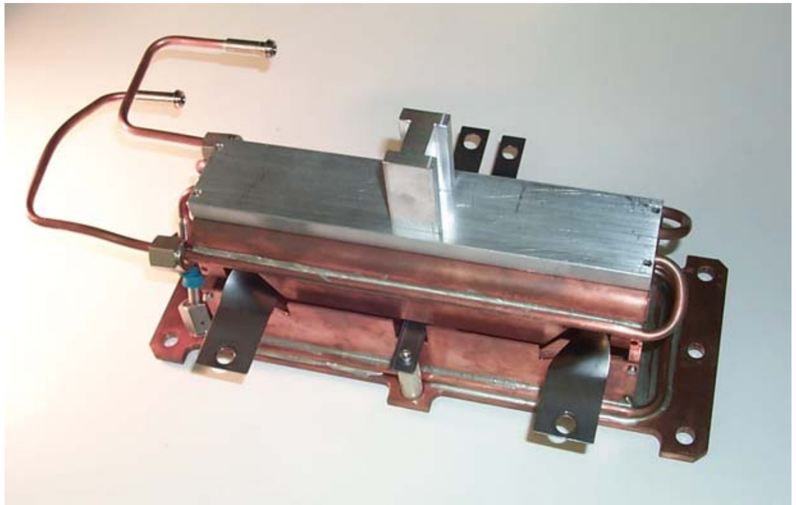
- **2008 (July): Rotating beam on annular targets (towards 100 μA)**
- **2008 (Sept): Actinide target tests**
- **2008 (Fall?): Composite oxide/metal foils (actively cooled targets)**
- **New ECR source in off-line tests**

ISAC Target Development

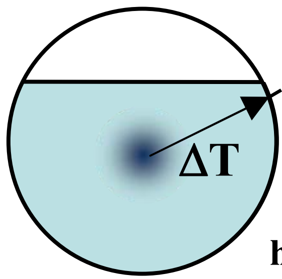
- Initial ISAC commissioning with 1-2 μA p^+
- Initial runs with resistive target heating & heat shields to maintain temperature
- Higher p^+ intensities required higher emissivity for passive radiative target cooling

ISAC Target Development





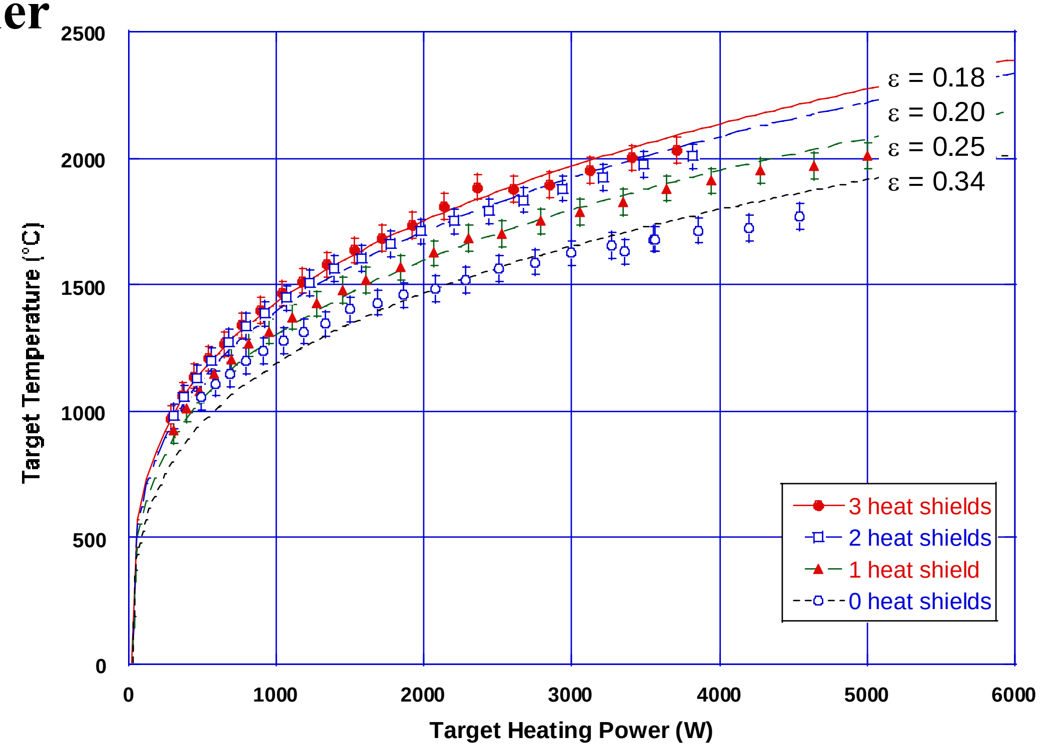
Increasing p^+ Current



- Metal target foils fabricated slightly oversize and ensure good thermal contact with target container

- Heat shields removed for higher emissivity → greater power dissipation

- **Result:**
  - ~ 7 kW power dissipation
  - Ta foil targets to 40 μA p^+
  - SiC pressed pellets to 15 μA p^+ (poor contact)



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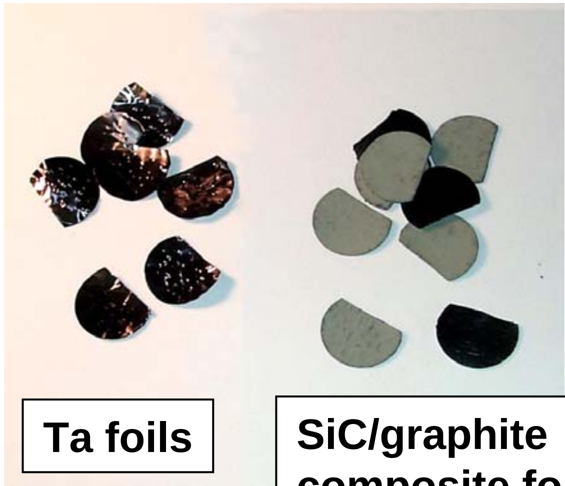
Increasing p^+ Current on Compound Materials

- Increase heat transfer of compound materials eg: carbides
- Slip cast powders onto flexible graphite sheet
  - Using binders, plasticizers, surfactants (~ 10% organics)
- Treat composite sheets as metal foils
- Result:
  - SiC, TiC, ZrC to 35 μA p^+



Composite Thermal Conductivity

- ZrC Thermal Conductivity
  @ 1900°C: ~ 0.4 W/cm·K
- 45% porous ZrC Thermal Conductivity @ 1900°C: ~ 0.14 W/cm·K
- exfoliated C_{gr} Thermal Conductivity
  @ 1900°C: ~ 0.52 W/cm·K

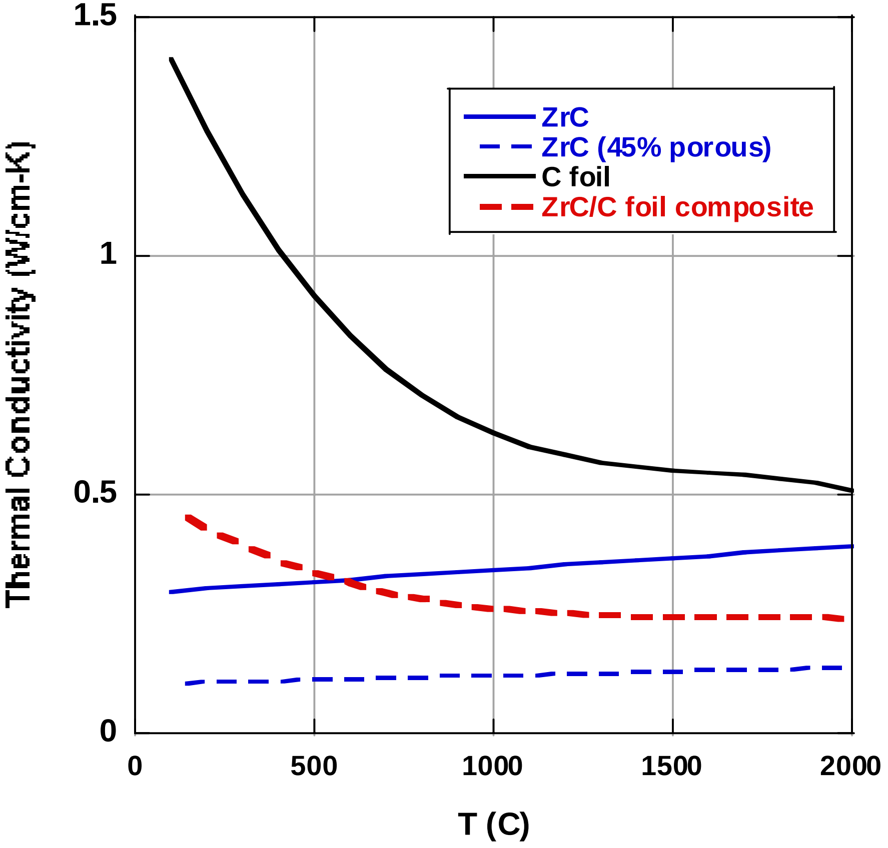
- Composite Thermal Conductivity:

$$\lambda_a K_a + \lambda_b K_b$$

where $\lambda_a \equiv$ volume fraction of component *a*

$K_a \equiv$ Thermal Conductivity of component *a*

- Composite ZrC/C Thermal Conductivity
  @ 1900°C: ~ 0.25 W/cm·K

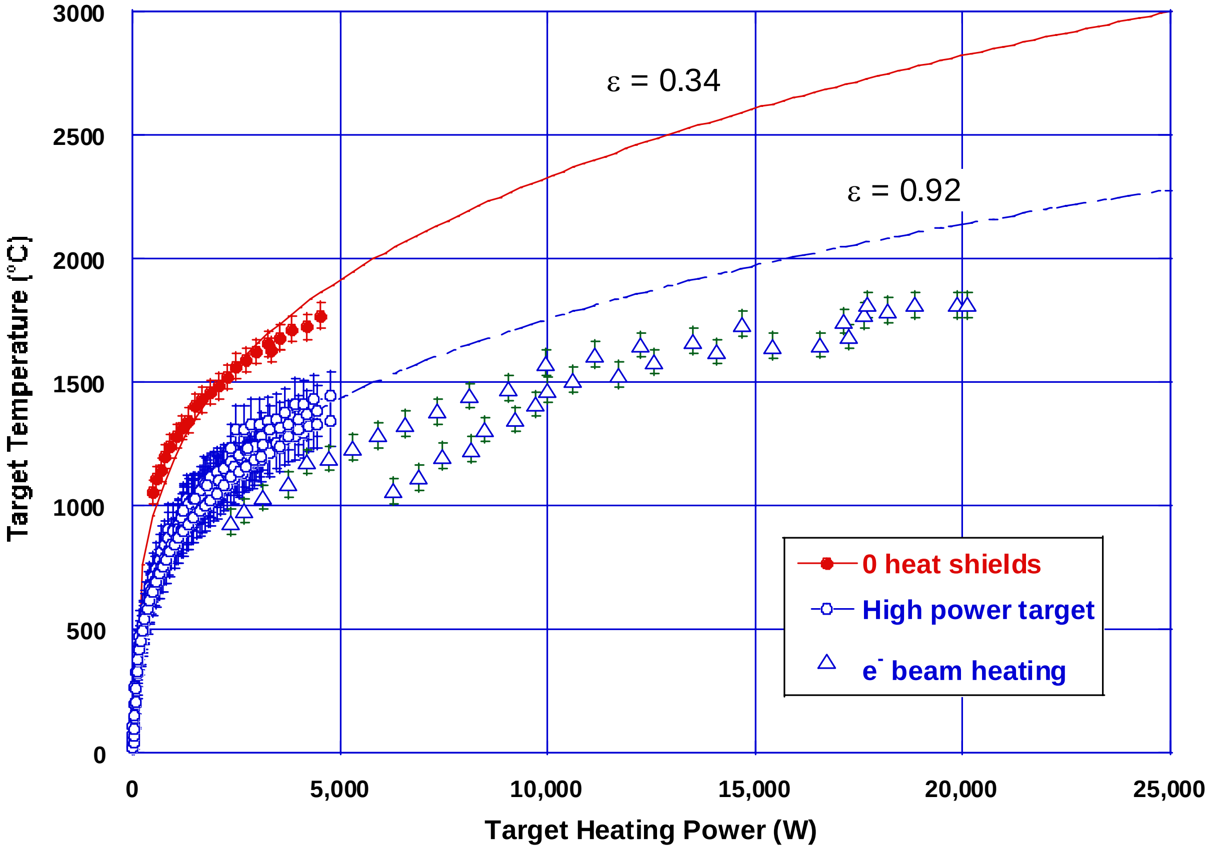


ISAC High Power Target Development

- An old pyrometer calibration trick:
  - A hot cavity with > 6/1 depth/diameter ratio approximates a black body
- So:
  - Add fins to a standard ISAC target with depth/spacing > 6/1
  - Heat target to diffusion bond fins to target tube for good thermal contact

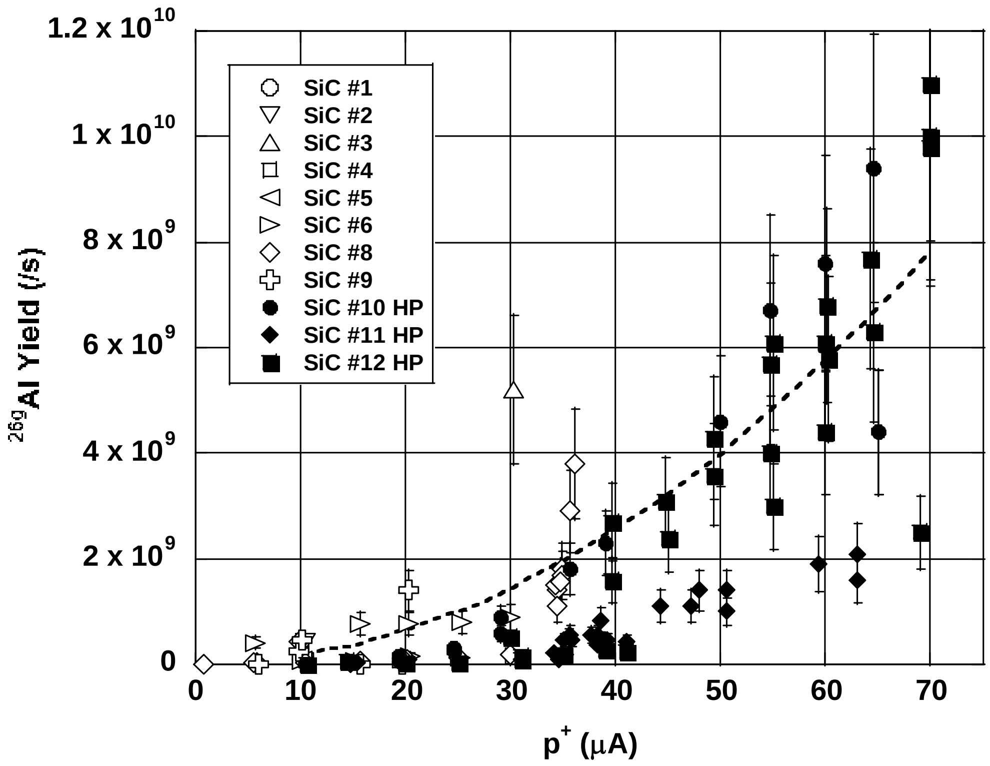
Result: enhanced radiative power dissipation

- **Black body ε = 1**
- **ISAC HP target ε = 0.9**
- **~ 25 kW power dissipation @ 2200º C**
  → 65-75 μA p^+ on SiC/C, TiC/C, Ta
- **BUT: oxides running ~ 1500 º C require active cooling**



Successively Improving Yields by Target Development

- SiC pellets:
  - 15 μA p^+
  - 7.7×10^8 $^{26g}Al/s$
- SiC composite foils:
  - 35 μA p^+
  - 3.8×10^9 $^{26g}Al/s$
- SiC composite foils in HP target:
  - 70 μA p^+
  - 1.1×10^{10} $^{26g}Al/s$



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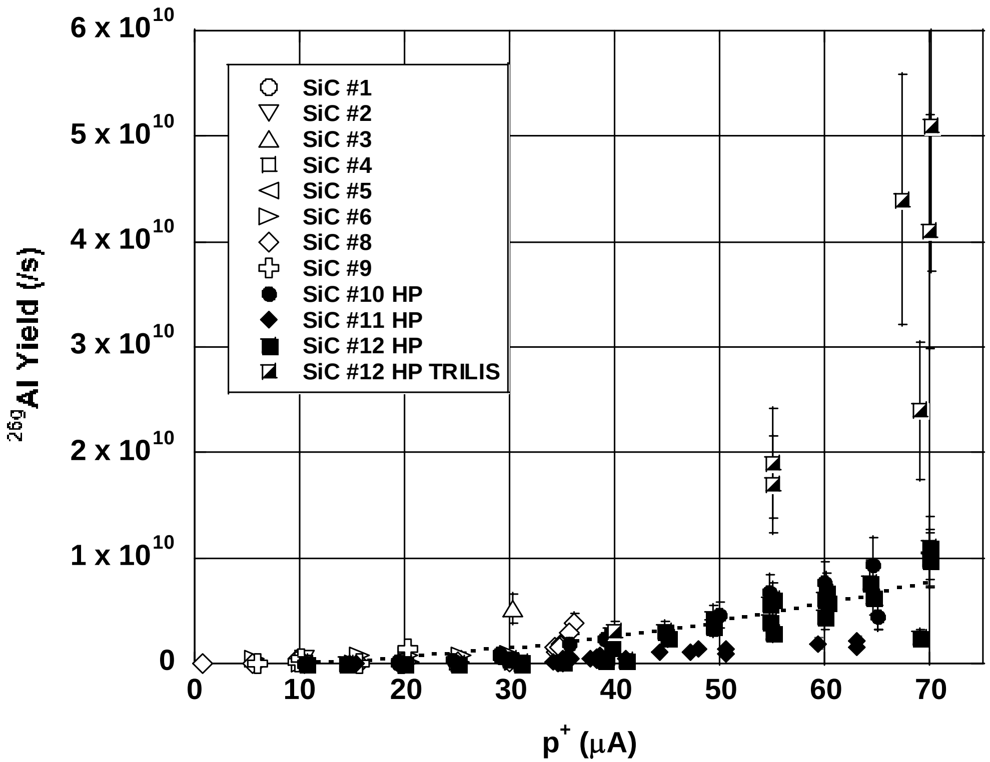
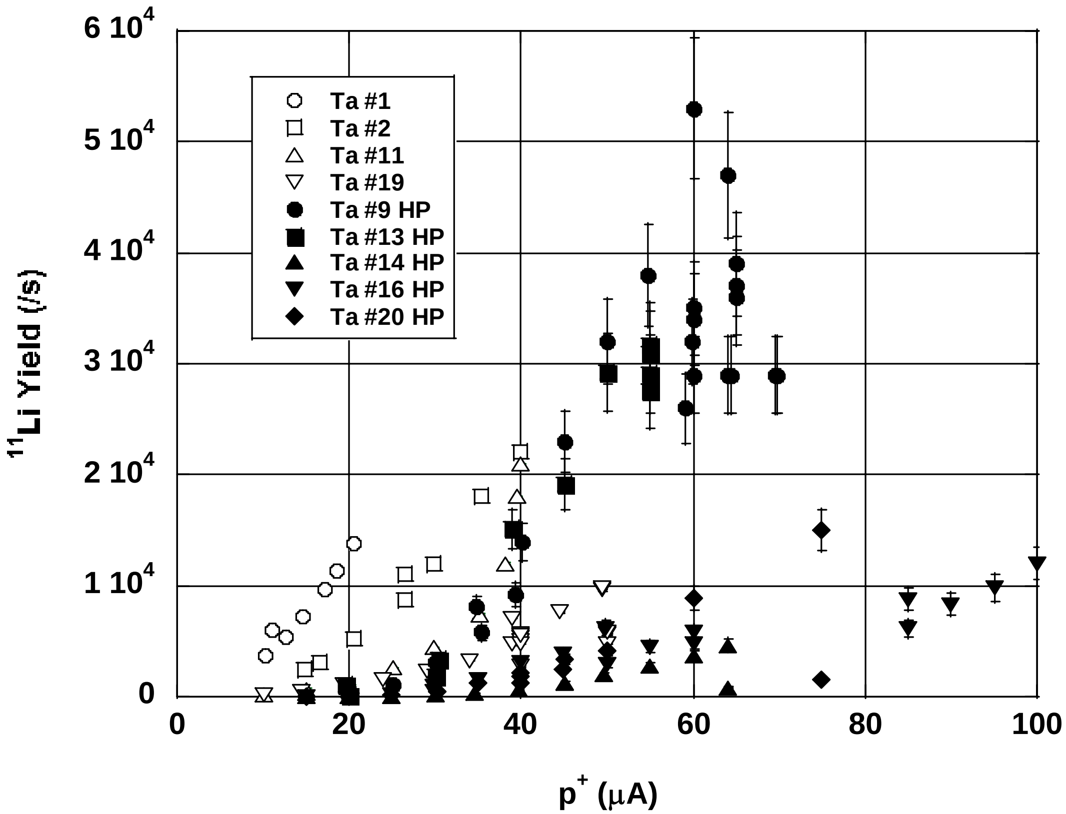
- **SiC pellets:**
  - **15 μA p^+**
  - **7.7×10^8 ^{26g}Al/s**
- **SiC composite foils:**
  - **35 μA p^+**
  - **3.8×10^9 ^{26g}Al/s**
- **SiC composite foils in HP target:**
  - **70 μA p^+**
  - **1.1×10^{10} ^{26g}Al/s**
- **With the right ion source (TRILIS)**
  - **70 μA p^+**
  - **> 5.1×10^{10} ^{26g}Al/s**



Problems with Dense ISAC Ta Targets

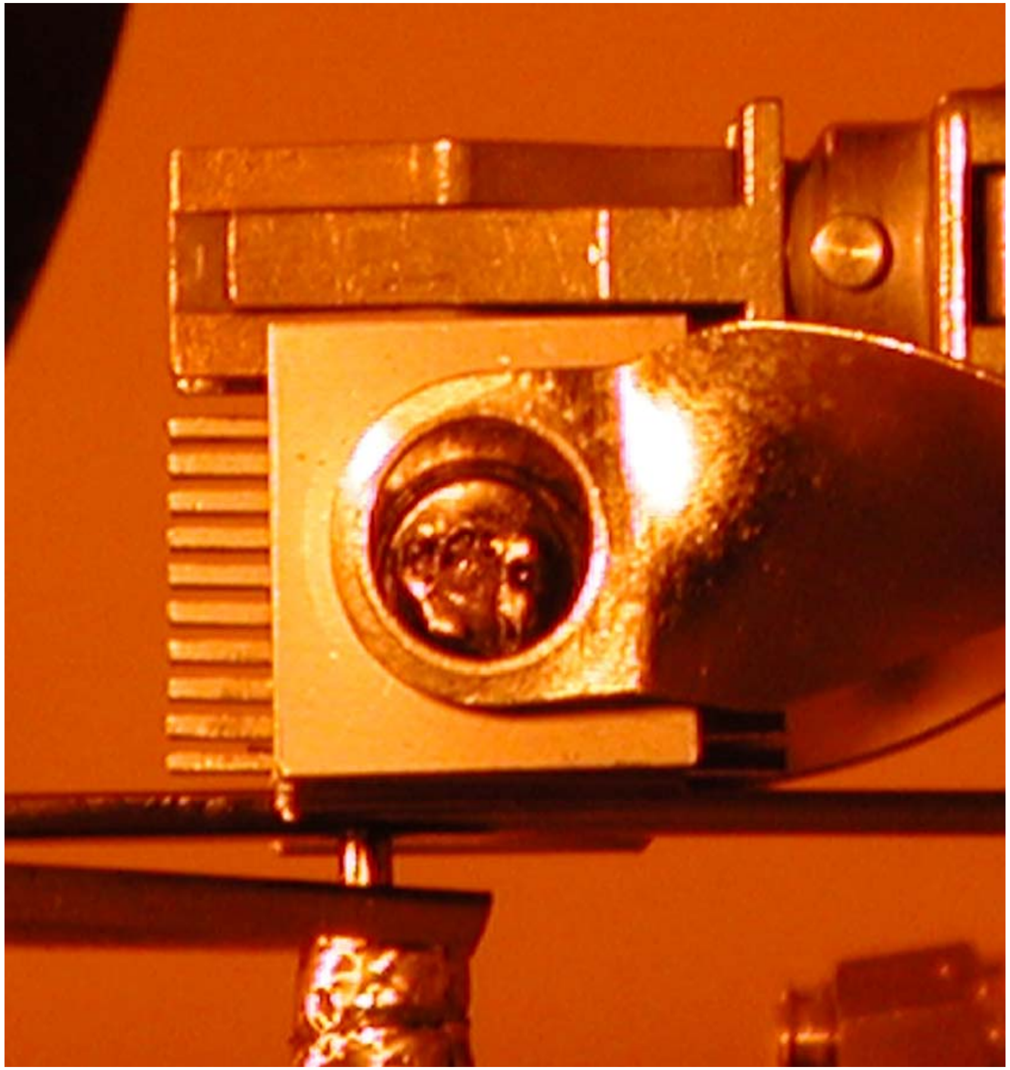
- Yields from 1st HP target dropped above 60 μA p^+ and did not recover
- Subsequent ^{11}Li yields inconsistent & lower than some standard target yields
- p^+ beam density appears to be a factor
- Radiation enhanced diffusion effects seem to be lower with a broader p^+ beam spot



What Was Wrong?

- **Initial Examination:**
  - **Looks OK**

- **End On View:**
  - **Several spots of melted Ta**
  - **p+ beam spot could not have been 8 mm FWHM**
  - **p+ beam spot must have been ≤ 2 mm FWHM to melt Ta**



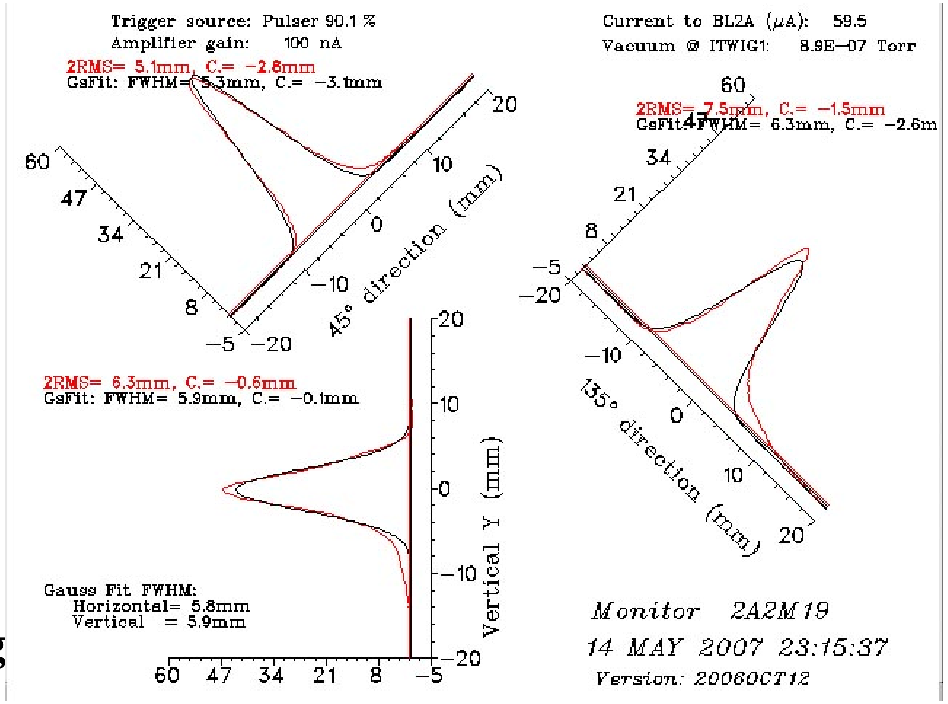
Problem with p^+ Beam Density

- ISAC p^+ profile monitors were not calibrated
  - No p+ size information
  - No p+ position information
- Temperature drop from beam center to target edge:

$$\Delta T = \frac{\rho \Delta I}{2\pi K}\left[1.204 + \ln\left(\frac{r}{r_0}\right)\right]$$

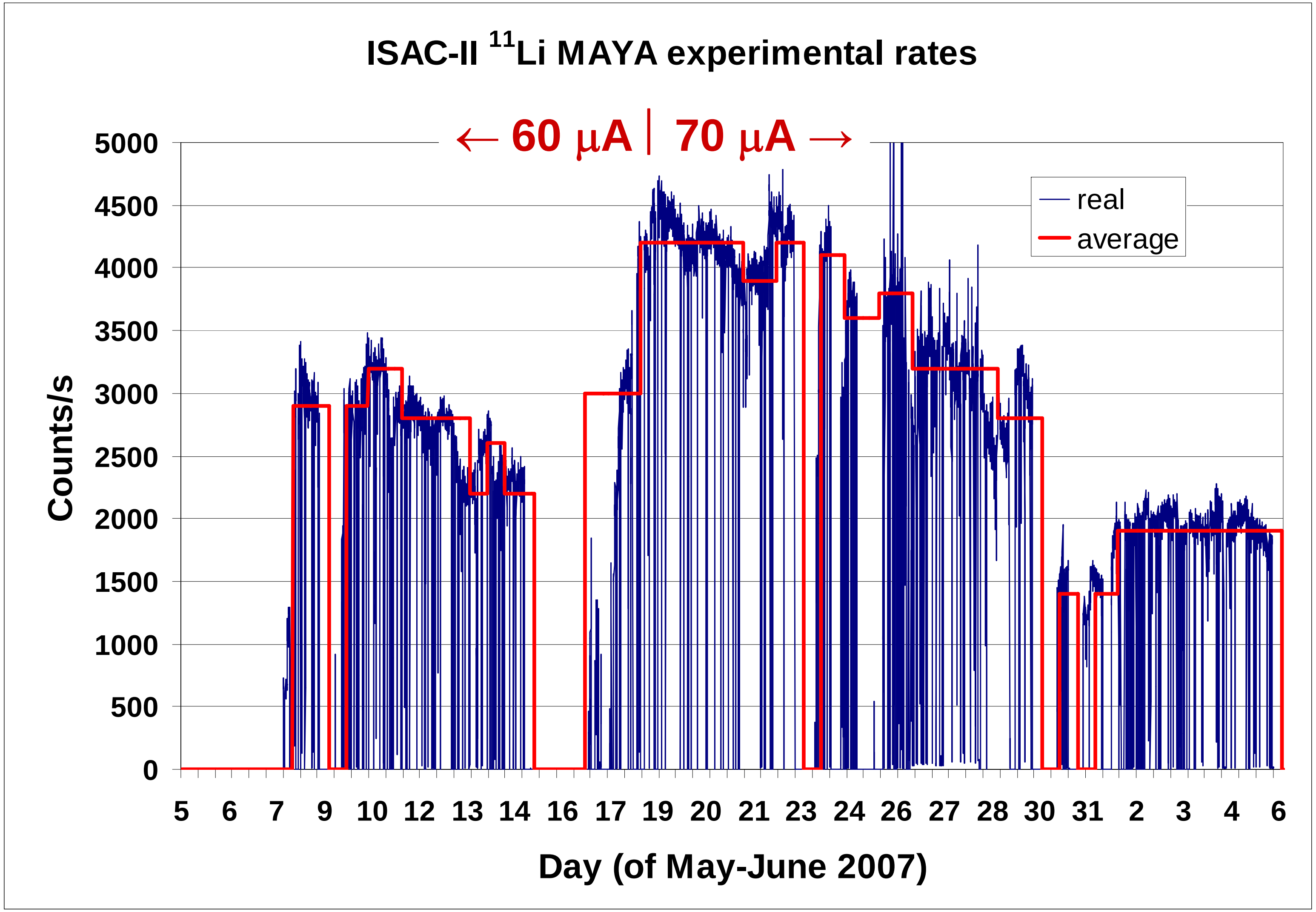
- $\rho \equiv$ density (g/cm³)
- $\Delta \equiv$ Energy loss rate (MeV·cm/g
- $I \equiv p^+$ current (μA)
- K ≡ Thermal conductivity (W/cm·s·K)
- $r \equiv$ distance to target wall
- $r_0 \equiv$ HWHM of p^+ beam spot

ISAC p^+ Beam Profile Monitor



- small p^+ spot close to wall may be OK
- small p^+ spot in center may melt target
- an annular rotating beam might solve the problem

Target Aging Effects



Cumulative Target Damage Problems

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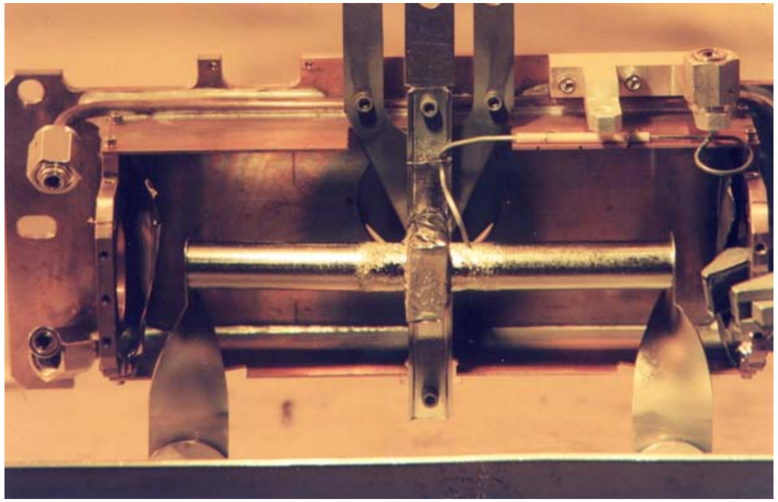
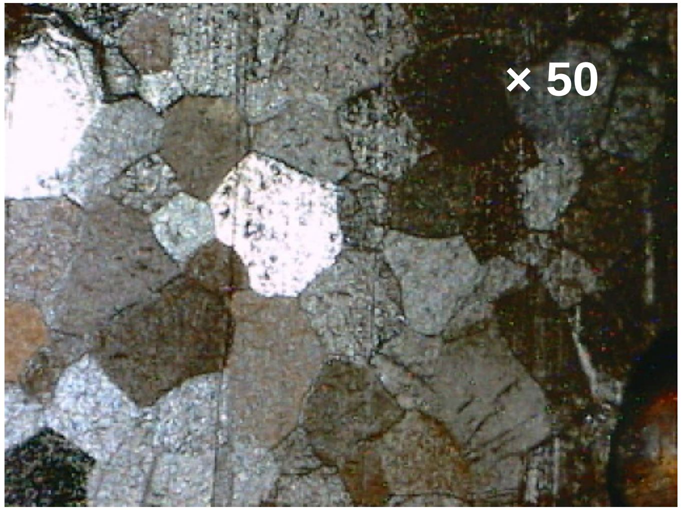
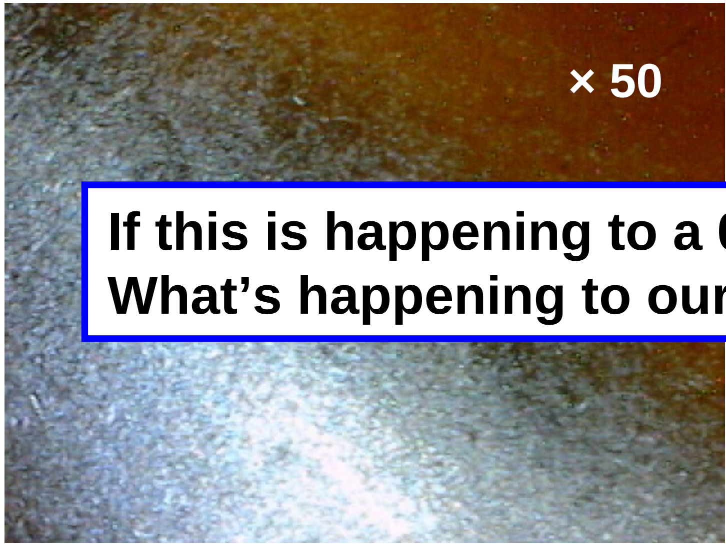
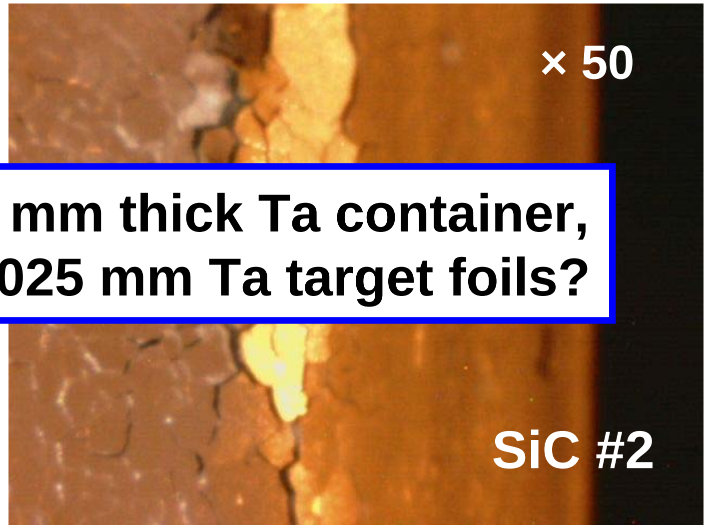
ISAC Target Ta #6 13,858 μA·hrs, 3.6 × 10^{20} p^+, 40 μA







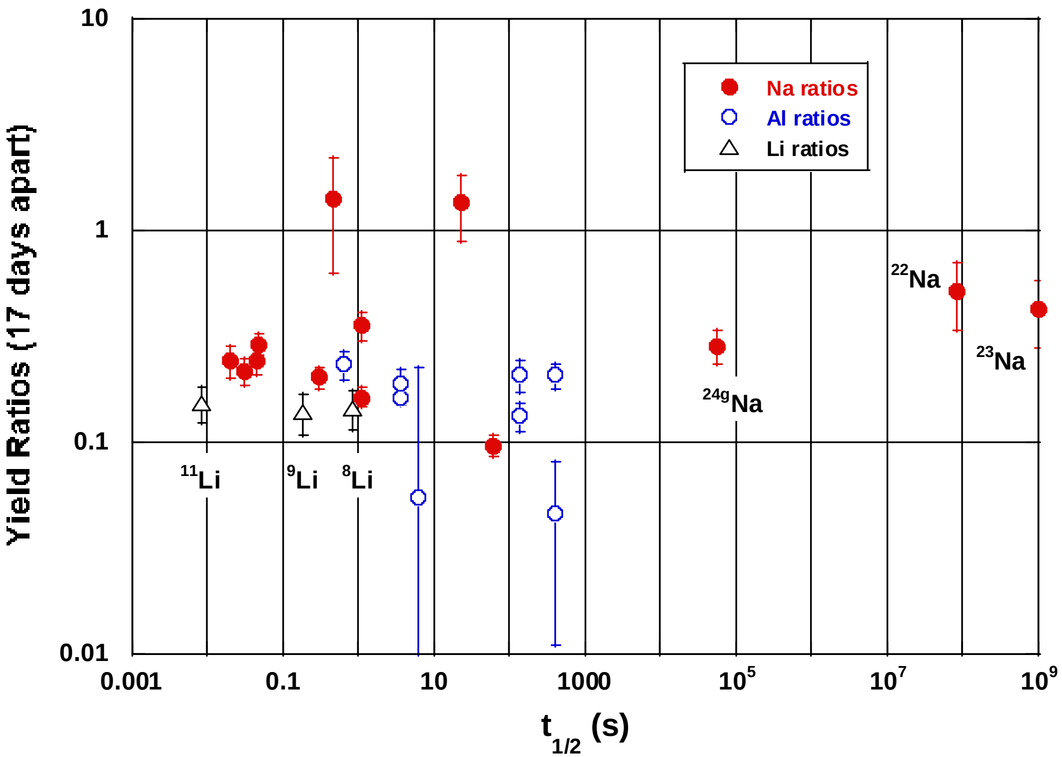


**If this is happening to a 0.5 mm thick Ta container,
What's happening to our 0.025 mm Ta target foils?**

Target Aging Effects

- Ta #20 HP:
  - ~ 42,000 μA-hr
  - 9.4×10^{20} p^+ total
  - 0.1% of Ta target material transmuted by nuclear reactions
  - 47.1 mg of 46.3g Ta transmuted

- Average 79% yield decrease
  - Not element dependent (not an ionization effect)
  - Not half-life dependent (not a diffusion effect)
  - Possibly due to loss of integrity of target container



*Could have implications for long running periods at high p^+ currents

In Conclusion

- $\leq$ 75 μA p^+ intensities demonstrated
- $\geq$ 100 μA p^+ intensities in sight
  - 200 μA p^+ is a reasonable goal
- High p^+ intensities are not a problem for traditional RIB ion sources
- Beam size & position are critical at high p^+ intensities
- Target radial thermal gradients can be a problem
  - ΔT ~750º C @ 70 μA 2200 º C max (bad for high ΔH_a elements)
  - Annular foils/rotating beam could solve this
- Target longevity is compromised by grain boundary segregation of impurities
  - Enhanced by high temperature
  - Enhanced by radiation enhanced diffusion
  - Is it possible to beat? Maybe?
    - If not, need to change targets frequently